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MORPHOLOGICAL CONSIDERATIONS IN LINGUAL APPLIANCE DESIGN:
A DESCRIPTIVE STUDY

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at the
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MORPHOLOGICAL CONSIDERATIONS IN LINGUAL APPLIANCE DESIGN:
A DESCRIPTIVE STUDY

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INTRODUCTION

Orthodontists as far back as Edward Angle have experimented with lingual attachments. Refinements in bonding technology and the development of more resilient orthodontic alloys and wires in recent years have made the lingual approach to the orthodontic¹ correction of malocclusion more feasible. However, the majority of the clinicians who are currently utilizing lingual appliances have essentially used trial and error methods based upon their experience in buccal therapy. A more orderly approach in the development of this relatively new area of orthodontics would be to utilize bioengineering principles to develop and modify⁷ appliance design as suggested by Burstone in relation to buccal orthodontic techniques.

Some of the problems associated with the use of the same mechanics for lingual orthodontic treatment as those used on the buccal are:

1. Difficulty with visibility and archwire insertion
2. Reduced anterior interbracket distances on the lingual
3. Difference in arch curvature on the lingual
4. Different geometry of attachments on the lingual requiring step-in bends between the cuspid and bicuspid and between the bicuspid and molar
5. Different anatomy of the palate and lingual vestibule as compared to the buccal vestibule

It may be that the use of a lingual segmented arch technique^{8,9} similar to that presented by Burstone for use on the buccal could alleviate the first problem associated with difficulty of

archwire insertion to a certain extent. A segmented approach would reduce the frequency of archwire replacement and would make insertion easier in situations where only the anterior or the posterior segments needed to be replaced rather than an entire mushroom shaped continuous archwire. A lingual segmented arch technique would also allow for the use of different wire configurations in the anterior and posterior segments also as described by Burstone¹⁰ in relation to buccal therapy. This concept could help to solve the second problem of reduced anterior interbracket distances on the lingual.

However, in order to begin a biomechanical approach to lingual appliance design utilizing segmented mechanics or any others, it is necessary to first solve the three remaining⁴ problems stated above. Angle stated it very well when he said:

"...we must not lose sight of the importance of the dental apparatus as a whole and the important relations not only of the two arches to each other, but of the individual teeth to one another. The shapes of the cusps, crowns, roots, and the very structure are all designed for the purpose of making occlusion the one grand object, in order that they may best serve the purpose for which they were designed,..."

From a lingual viewpoint, many of these relationships are altogether different and must be re-evaluated.

OBJECTIVES

The specific objectives of this descriptive study therefore include:

1. Quantitation of lingual interbracket distances for each two-tooth segment from cuspid to second molar
2. Quantitation of the step or "in-out" distance for each two-tooth segment from cuspid to the second molar
3. Quantitation of the lingual arch width from the cuspid to the second molar at the level of the bracket
4. Assessment of the palatal contour in frontal section at each lingual attachment from cuspid to second molar

These measurements will increase the understanding of the lingual arch curvature and interdental relationships. They will also help to define the allowable shape and dimensions of lingual appliances and space closing devices and their orientation in space relative to the dentition.

LITERATURE REVIEW

In recent years, there has been a growing interest in the area of lingual orthodontics. This has benefited the orthodontic profession as a whole because it has increased public awareness and acceptance of adult orthodontic treatment.^{6,43}

²⁰
Fujita has reported beginning research on a modern lingual orthodontic technique as early as 1971. His purpose was to develop an orthodontic treatment technique which would be both hygienic and esthetically pleasing by making use of orthodontic forces coming from the lingual and palatal surfaces of the teeth.^{1,28,45}

In about 1973, Kurz started experimenting independently in his practice with lingual appliances created by modifying labial appliances. He began working with Ormco in 1976 on a near-conventional edgewise approach to lingual mechanics. One of the initial criteria was to deviate as little as possible from well-established edgewise principles, using a straight-wire approach if possible. Topographical contour maps of the teeth and adjacent lingual anatomy were made from models of finished orthodontic cases. Intertooth relationships were also studied. It was found that, in the absence of short clinical crowns, there was no problem establishing a straight archwire plane which was parallel to the occlusal plane in most cases.

Lingual bracket design necessitated the calculation of lingual values for torque, angulation, rotation, pad profile and contour and in-out relationships. This was done by relating lingual determinants to labial tooth anatomy. These studies were done using about 400 teeth resembling the anatomical form

published by Wheeler in his textbook of dental anatomy. This data yielded high standard deviations. Rudimentary cusps or other anatomical variation would add even greater variance. Large torque changes were noted with only minor variation in bracket height. Further topographical mapping of lingual crown morphology was conducted in 1979.²⁸

The initialOrmco lingual appliance prototype has been modified as additional laboratory and clinical data has become available. This is due, in part, to the formation of the Lingual Task Force in 1980. It began with seven members and had¹ increased to 550 by 1982. Members of the Task Force have written several articles describing changes in bracket design, problems and advances in mechanotherapy and patient response to lingual appliances.^{1-3, 21, 28, 29, 40, 44, 45,46}

In about 1979, Kelly²³ began working with Unitek on what they thought would be the ultimate straight wire lingual appliance, no bends required. The cuspid bracket was cantilevered away from the tooth to eliminate the need for an offset bend between the cuspid and first bicuspid. They were not able to work out problems with torque and returned to the mushroom arch design. The Unitek lingual appliance has also undergone a series of modifications since its initial design.

Paige has reported success with the use of a Begg bracket on the lingual. He currently uses a Unipoint combination bracket (Unitek). He does not feel that a preangulated, pretorqued edgewise bracket design is practical at this time because the

amount of torque supplied by the bracket is very sensitive to occlusal-gingival placement on a highly variable lingual tooth surface. He does not think that indirect bonding is a satisfactory long-term solution because it takes too much control away from the orthodontist.

The vast majority of clinicians who are currently using lingual brackets are using lingual brackets are using conventional (labial) mechanotherapy techniques for retraction and consolidation. Sliding mechanics, closing loops or a combination of the two are used by most.^{20, 23, 1, 2, 35, 39}

The majority of clinicians have also reported the same problems during the course of treatment. There is a general agreement that lingual appliances have a rapid bite-opening effect due to the occlusion of the lower incisors on the maxillary incisor bracket bite planes. The use of highpull headgear should be considered in cases in which bite-opening is contraindicated due to an open bite tendency, an already convex profile or a Class II situation in which anchorage is critical.

Another problem commonly reported is that of arch width expansion. Alexander, et al² attributes this to insufficient constriction of the archwire in the anterior segment. Gorman, et al²¹ feels that the initial posterior desclusion and the tendency for mesiobuccal molar rotation during space closure are also contributing factors. The use of a transpalatal arch has been implemented by many clinicians to counteract this problem.²³ Kelly, on the other hand, has found the problem to be constriction and not expansion. He explains it with the idea

that the lingual attachments cause the patient to keep his tongue back away from the incisors. As a result, the lips are the overriding force and thus constrict the arch.

¹⁸ Fujita ³⁵ and Paige, among others, have noted a problem with mesiodistal tipping of teeth and/or difficulty with uprighting of cuspids and bicuspid at the extraction sites. Fujita incorporates an auxiliary groove set in an occlusogingival direction in his bracket design to counteract this problem, while Paige advocates the use of uprighting springs or a power arm (Rocky Mountain/Orthodontics).

As previously pointed out, accurate placement of lingual brackets is another source of great difficulty. In addition to the problem of anatomical variation, there are a variety of techniques for determining bracket height. ³⁵ Paige places his bicuspid brackets as far gingivally as possible resulting in placement of the incisor brackets about 5mm from the incisal edge and the molar brackets about 3mm from the ³⁶ palatal cusp (measured along the lingual surface of the tooth).

⁴⁵ Smith, et al recommends placement of the gingival edge of the bracket about 1.5mm from the gingival crest. They utilize a device called the Torque and Angulation Reference Guide to transfer the bracket position from the labial surface of each tooth to the lingual at a given bracket height, customizing torque and angulation. In-out discrepancies are compensated for in the bracket base with the addition of Advance adhesive.

^{19, 20} Fujita constructs a model simulating the post-treatment situation. Bracket position is measured using a surveyor or the

Fujita arch as a guide. The first molar bracket is placed 3-4mm from the cusps and the incisor brackets are 5-6mm from the incisal edge measured from the occlusal plane. The bicuspid brackets are placed relative to the incisors and first molars at 4-5mm from the occlusal plane.

²⁴
Kelly places the maxillary central incisor brackets 1mm below the midpoint of the anatomic crown. The molar bracket height is determined by the position of the labial bracket. A line is then drawn connecting the molar and incisor height markings to determine the height of the remaining brackets.

¹⁴
Diamond stresses that bracket placement must be planned to compensate for tooth form and shape. Labiolingual tooth thickness and the slope of the lingual surfaces must be closely evaluated in order to align the slots so that a flat plane of occlusion will be established.

For the most part, it is apparent that the development of lingual orthodontic therapy is following a course of gradual modification based upon knowledge of crown morphology and the results of clinical trials. Appliance modifications have been made to make archwire insertion easier, to increase patient comfort and to improve adaptation of the bracket base to the tooth surface. Bracket specifications have been modified as treatment difficulties became apparent.

More resilient archwires have made anterior bracket engagement with reduced lingual interbracket distance easier.
23, 46 ⁴⁵

Smith, et al noted that a resilient archwire archwire needed for anterior bracket engagement may be too flexible for

the buccal segments during space closure, leading to undesirable side effects. They also mentioned⁴⁶ that newer archwire materials allow for fewer archwire changes as presented in the variable modulus concept of Burstone;¹⁰ dimension and cross section can remain fairly constant while stiffness is varied. Perhaps this concept should be carried one step further to the use of a segmented arch^{8, 9} approach to lingual orthodontics. This would allow for the use of different wire configurations in the anterior and posterior segments, and would restrict some archwire changes to replacement of only anterior or posterior segments rather than an entire mushroom arch.

One other pioneer in lingual orthodontics who should not go unmentioned is Fontenelle,¹⁶ who claims adherence to the principles of Burstone in the development of his appliance. He has described an appliance with a passive unit consisting of a cast bonded splint in the anterior segment and a rigid transpalatal arch in the posterior. The active unit consists of bilateral palatal coil springs connecting the anterior and posterior passive units so that the force is approximately through the center of resistance. A modified version with palatal extensions on the maxillary cuspids is used for cuspid retraction. This appliance has the advantage of being a frictionless system.¹¹ It is also very different from any conventional labial appliance. Perhaps such a design is appropriate given that many interdental and intra-arch relationships are entirely different when viewed from the lingual.

Sved divides the mechanical phase of orthodontics into three steps:

1. The study of normal form
2. The correlation of the abnormal and normal forms
3. The study of mechanical devices used for the correction of abnormalities

In order to develop mechanical devices specifically for use in lingual orthodontic treatment, it is necessary first to study and assess normal form.

Obtaining normal form in his treatment has, of course been the goal of the orthodontist since the birth of the profession. There has been a search throughout the literature to define normal form in skeletal relationships, soft tissue contours, dental anatomy, occlusal relationships, arch form and palatal contour, to name a few areas. These studies, however, were not done with a lingual appliance in mind.

The study of the "dental apparatus"⁴ from a lingual viewpoint has become more important in the last ten to fifteen years. As mentioned, Ormco^{1, 28, 45} has done some work with topographical contour maps, primarily limited to the crowns of the teeth. They have related lingual crown morphology to labial crown morphology in designing their appliance. They have also done some analysis of intertooth relationships. Very little of this data, or any other data, on lingual dental relationships is readily available in the literature.

A review of the literature of dental relationships from a labial perspective is in order. Many of the methods and results

obtained can be applied to a lingual study.

One area that relates somewhat to the present study is the analysis of dental arch form. Researchers have attempted to define the normal or ideal arch form with mathematical equations, geometric forms and computer-derived formulae. The majority of the techniques are attempts to define the curve of the anterior part of the dental arch.⁵¹ This curvature has been described as an ellipse,¹¹ a parabola,¹³ a trifocal ellipse² and a catenary.^{32,41}

The Bonwill-Hawley¹² formula places the incisors and cuspids on the arc of a circle with a radius equal to the combined widths of the six anterior teeth. An equilateral triangle is constructed from this circle, the base of which is said to be an estimate of the intercondylar width. The alignment of the posterior teeth is represented by a line from each condyle to the distal aspect of the canine on the same side. Although this technique is no longer accepted, many ideal archwires manufactured currently are based upon this design.

Williams⁵³ observed a constant 14:9 ratio between intercanine width and intermolar width (measured from the mesiobuccal groove) in "American type" individuals.

Stanton⁴⁷ found that most human arches vary only 5mm in width on each side of the midpalatal suture and 13mm in length (from buccal groove to upper incisal edge).

Currier¹³ used radiographs of 25 pairs of plaster dental casts of normal or ideal occlusions in his study of arch form. Points on the radiographs representing outer, middle and inner curves of the dentition were plotted and expressed as x and y

coordinates. The curves corresponded, respectively, to the buccal cusps and incisal edges, the central fossae and cinguli, and the most lingual aspects of the teeth. An attempt was made to fit each of the curves to an ellipse or a parabola using a least squares curve fitting program. The ellipse had a total smaller variance of fit to the outer curves in both arches, while the parabola had a total smaller variance of fit to the middle curves in both arches. Neither the ellipse nor the parabola exhibited a significant fit to the inner (lingual) curve of the arches.

In addition to defining arch form, researchers have sought to explain the principles influencing this form. A widely accepted notion is that there exists an equilibrium between tongue pressures and lip and cheek pressures. This has been contested by many studies, including the work of Proffit, et al.^{37, 38}

They found a wide range of lip and tongue forces in 19 adult subjects with similar dentitions.

³³

Meredith and Higley attempted to relate arch width to the widths of the face and head. No association was found.

Many researchers have, in a similar way, been searching for a means of defining palatal form and factors influencing this form. ³⁰ Lear recorded head posture during sleep in 7 adult males to look for a correlation with asymmetry of palatal and dental arch form. No correlation could be found.

²²

In about 1912, Gruenberg ²⁷ devised an apparatus for measuring symmetry or asymmetry of dental arches. Korkhaus presented an improved version of the device in 1930 to study

study palatal symmetry. The symmetrograph could transfer a traced curve on a model of the palate to millimeter paper with a mechanical writing device. It was used to study asymmetries and to detect alterations of the arch during treatment. An additional aid was sometimes used in conjunction with the symmetrograph. It was described as consisting of "a great number of fine bars which are kept together by two screws." The bars dropped and conformed to the desired curve of the palate.

⁵⁴
Lebret used the symmetrograph of Korkhaus to study the growth of the palate on dental casts. Tracings of median sagittal and transverse contours at various developmental stages were studied in thirty longitudinal series of casts. The rugae were used as a reference for superposition. The transverse shape of the of the palate in the sample studied was parabolic except in two individuals with a "V-shaped" palate. Palatal dimensions in the males exceeded those of the females.

⁴⁹
Talbot had noted a marked difference between intermolar width of males and females in 1892. He studied the height of the palatal vault and tried to explain variation as a measure of intelligence, with high and narrow vaults being indicative of superior intelligence.

³¹
Lear also used a symmetrograph to measure and transfer the location of the midpalatal line in his analysis of symmetry of the palate and maxillary dental arch. Silhouettes of the transverse palatal contour were made with half-round wax strips at right angles to the midplane between the right and left premolar contact regions and intermolar regions. He also waxed a

continuous clasp at the level of the interdental papillary crests from the left second molar to the right second molar. These wax patterns were stabilized with sprues and cast in technique metal. The castings were radiographed and traced for comparison of the shape of the left and right sides of the palate and of the arch form. In two adult males with neutroclusion and a regular alignment of teeth, superposition of palatal contours in premolar and molar regions showed a close left-right correspondence in shape, although the right side was broader in the second subject. The later exhibited a 4.4mm left-right discrepancy in the premolar region and a 6.2mm discrepancy in the molar region.

42
Shapiro, et al noted the need for a description of normal palatal form as a diagnostic aid for syndromes of the head and neck. They measured palatal width as the distance between the maxillary first molars at the cervical line. Palatal height was measured from the fovea palatinus to a horizontal reference plane established by the cervical lines of the first molars and the labial point of the incisive papilla. A "palatal index" was derived determined by the formula: $\text{Height/Width} \times 100$. In 123 adult females, the mean index was $39.0 \pm 0.6\text{mm}$ with a standard deviation of 7.04. In 101 adult males, the mean index was $43.1 \pm 0.9\text{mm}$ with a standard deviation of 9.06.

26
Knott and Johnson noted a lack of knowledge of normal palatal height and shape with respect to (1) the range of variability and (2) change during the childhood years. They studied the height, width and depth of the palate in girls longitudinally from 5 years of age to 17 years of age.

Erickson described a need for an objective, quantitative assessment of palatal form. Points in three-dimensional space were measured on the palate and were fitted by a least-squares multiple regression equation.

34

Moyers, et al at the University of Michigan have done an extensive longitudinal study of dental casts. The casts were digitized by means of an Optocom, an instrument designed and constructed at the University of Nymegen. A dental cast can be precisely placed on a based on a sliding table for alignment with the crosswires of a microscope mounted over the table. The position of the table is recorded in tenths of millimeters and the information is transmitted through a data converter to the Teletype. Among the data recorded with this device were upper and lower arch widths from canine to second molar from 3 to 18 years of age. It was noted that right and left halves of the arch are not equal and were under further study. Sexual dimorphism was noted as being significant at either the 1% or 5% level of confidence in at least one age group of the permanent dentition for every cross section. It should be noted that the sample size at 18 years of age for arch width measurement was quite small: 11-13 for males and 3-6 for females. Palatal height, width and depth were studied relative to rugae points. Palatal height was also measured from the functional occlusal plane to the most anterior point on the midpalatal raphe and to the most posterior point. The most noteworthy sexual dimorphism in these measurements was found in the height from the functional occlusal plane to the most posterior point on the midpalatal

raphe with a significant difference in every age group from 15-18 years of age. The sample size in these age groups was 10-37 for males and 5-33 females, the lowest numbers corresponding to the 18 year-old group.

25

The method of Klami and Horowitz²⁵ has been used as a model in the present study. In their analysis of palatal asymmetry in children with posterior dental cross-bite, they used an adjustable carpenter's template (Figure 1) to record vertical measurements on dental casts. This instrument consists of pins which are 0.75mm in diameter. The appearance is quite similar to²⁷ the "fine bars" described by Korkhaus for use in conjunction with the symmetrograph. Measurements by Klami and Horowitz were recorded at 2mm and 4mm from each side of the midline in three transverse sections. They reported that measurements closer to the alveolus show too much variation. Measurement error was found to be 0.28mm.

MATERIALS AND METHODS

The material for this study consisted of study models taken from ten adult male patients and ten adult female patients. The decision was made to limit the sample to adults because the vast majority of lingual orthodontic patients are adults. It was a requirement that the patients had no history of prior orthodontic treatment and that they had reasonably well-aligned teeth. Minimal crowding and small deviations from a Class I molar relationship were acceptable. All patients were volunteers and were employees or students at the University of Connecticut Health Center or friends of the same. The mean age of the male sample was 29years 9 months (29:9) with a range of 24:4 to 43:7. The mean female age was 27:3 with a range of 21:0 to 34:6. The resultant combined mean age was 28:6. These values as well as a description of the occlusal characteristics of the sample can be found in Table 1.

Upper and lower alginate impressions and wax bites were taken of each patient. They were poured immediately in orthodontic stone following the manufacturer's instructions for water-powder ratio and mixing time. These models were then trimmed with the bases parallel to the lower plane of occlusion or the plane from the mesial cusps of the first molars to the incisal edges of the anterior teeth.

Medial-Lateral Sections

The lingual contour of each study model was recorded by using an adjustable carpenter's template (Figure 1) as used by Klami and Horowitz.²⁵ The pins of the device are 0.75mm in

diameter and can be readily adapted to the surface of the model as shown in Figure 2. Contour registrations were made by holding the device perpendicular to the base of the model and oriented so that the vertical pins of the device were perpendicular to a line joining the lingual cusp tip of a tooth with the lingual cusp tip of the contralateral tooth. Medial-lateral sections were registered in this manner for upper and lower cuspids, first and second bicuspid and first and second molars. The location of the midpalatal raphe in the upper arch was recorded as well as the gingival margin for every tooth.

Unfortunately, this method was not adequate to describe the lingual anatomy in the lower arch due to the frequent finding of a negative contour of the lingual anatomy. Values for the lower arch were therefore not included for this portion of the study.

Diagonal Sections

It was necessary to modify the technique for an additional registration of the contour in the area of the maxillary cuspid. Due to the fact that this tooth is located at the corner of the arch form, a medial-lateral section does not include the lingual bracket position. It was necessary to find a universal method of recording the palatal anatomy from the cusp tip down the long axis of the tooth and onto the palatal mucosa. This data would be meaningless if each registration had a different point of intersection with the midpalatal raphe. There would be no way to combine data from different patients or from the right and left cuspids of the same patient. For this reason, occlusal photos of the models were used to determine an average point of inter-

section with the raphe. This was found to be at a point a little less than half the distance between the first and second bicuspid. Diagonal sections at each of the maxillary cuspids were then registered by orienting the device from the cusp tip to the intersection of the midpalatal raphe and the line joining the lingual cusp tips of the right and left first bicuspid. It was again perpendicular to the base of the model and to the occlusal plane.

Recording of Measurements

Each of the described registrations of the device was photographed on a sheet of millimeter graph paper using a tripod and slide film (Figure 3). It was necessary to have a plexiglass holder made in order to place the pins of the device flush with the graph paper eliminating shadows (Figure 4). The right and left cusp tips were placed along the same horizontal line of the graph paper and the pins were checked for parallelism with the vertical lines of the paper. Each photograph contained a label indicating the patient number, the teeth being recorded, and the pin number of the gingival margin. The cusp tip was counted as pin number one. An example appears in Figure 5.

The slides were projected for measurement purposes so that 1mm on the graph paper was enlarged to 4mm on the screen. This made it possible to estimate the length of each pin to the nearest 0.25mm. Vertical pin measurements were recorded in tables with fixed horizontal measurements corresponding to 0.75mm pin diameter. In this way, horizontal and vertical coordinates

of points on the palatal contour were generated at each cross section for each of the twenty patients.

"Bracket" Placement

The next step was to locate the position of the lingual brackets on these contours. Each model was surveyed as shown in Figure 6. A straight line was etched corresponding to the best fit to a line through the brackets. The previously mentioned guidelines for lingual bracket placement were taken into consideration. A 1/16" stainless steel bead was glued on the lingual of each tooth at the position of a lingual bracket. This was placed on the surveyed line whenever possible, but sometimes had to be adjusted vertically up or down in cases with a pronounced curve of Spee or a slightly deep bite. These variations in position were noted. The vertical distance from the lingual cusp tip to the center of each bead was measured perpendicular to the plane of occlusion to the nearest 0.25mm. This was done as accurately as possible using the surveyor, a straight edge placed across the arch from lingual cusp tip to lingual cusp tip and a Boone gauge which was sectioned to allow its use on the lingual without interference.

All forty models were photographed with the occlusogram⁵⁰ camera in the University of Connecticut Orthodontic Clinic, checking cusp tip markings for visibility. A millimeter grid was placed on the occlusal surfaces as a check for 1:1 reproduction. Using these photographs, it was possible to measure the horizontal distance along the occlusal plane from the lingual cusp tip to the bead position for each tooth using a Boley gauge.

These distances were measured to the nearest tenth of a millimeter.

Using the vertical and horizontal measurements just described, it was possible to locate the bracket positions in each of the sections of palatal contour generated with the carpenter's template.

In-Out

The next item of interest was the in-out measurement from each lingual bracket to the bracket of the adjacent tooth. A piece of acetate tracing paper was attached to each of the occlusal photos. An ideal form was drawn through the buccal cusp tips for each model photo. A line was then constructed from each bead to the arch form which was perpendicular to a tangent to this arch form at the point of intersection (Figure 8). Measurements were made with the Boley gauge along the constructed perpendiculars from the buccal cusp tips to the lingual aspect of the respective bead. Values of in-out were obtained for each two tooth segment by subtracting the measured distance for the distal tooth from the measured distance for the mesial tooth. A step from the cuspid to the first bicuspid would thus have a negative in-out value if the perpendicular distance obtained for the cuspid was greater than the perpendicular distance obtained for the first bicuspid. This negative value would indicate a step toward the lingual from the cuspid bracket position to the first bicuspid bracket position.

Interbracket Distance

Interbracket distance was also measured on the occlusal

photos with the Boley gauge as the shortest distance from the center of a bead to the center of the adjacent bead.

Arch Width

Arch width was measured at the level of the brackets (beads) from each tooth to the contralateral tooth. This was again done on the occlusal photos using the Boley gauge.

All of the data was then submitted for statistical analysis.

RESULTS

Medial-Lateral Sections

Vertical measurements in all medial-lateral sections were recorded for every pin position from the respective cusp tip to the midline. It should be recalled that the pins are 0.75 mm in diameter and the cusp tip was assigned a value of 0 mm both horizontally and vertically. For convenience, only the mean measurements and standard deviations for every second pin to a distance of 12 mm from the cusp tip are presented in the tables. After 12 mm the sample size began to decrease. In the first bicuspid sections, on at least one side in 5 patients (6 teeth total), the midline was located 12 mm horizontally from the cusp tip. This also occurred in sections of the other teeth as the minimum horizontal midline location was reached.

Horizontal measurements in Tables 2-7 are therefore presented in increments of 1.5mm, beginning at 1.5mm from the lingual cusp tip toward the midline and ending at 12mm from the cusp tip. This range should be more than adequate for any application to lingual appliance design in the area of the alveolus. The mean horizontal and vertical coordinates of the midline have been presented in each section for palatal arch considerations. The bracket position has also been located, along with the gingival margin. This data appears in the lower half of the table.

Tables 3-7 correspond to the medial-lateral sections for the maxillary cuspid to the maxillary second molar, respectively. As pointed out in the Materials and Methods section, the technique

was not adequate to describe mandibular lingual morphology in this manner. The data was first divided into subgroups according to sex and side of the arch. Mean vertical measurements are presented at each increment in horizontal measurement for the various sample subgroups. In other words, proceeding across each table from left to right, means and standard deviations can be found for right and left sides for males, for females, and for males and females combined. The last three columns contain means for right and left sides combined, first for males, then for females, and finally for males and females combined. The sample size, therefore, increases moving from left to right from 10, to 20, and finally to 40 in the last column. It should be recalled that the data in these tables was recorded to the nearest 0.25mm in all vertical measurements, while horizontal measurements were taken at fixed intervals of 0.75mm.

It is interesting to note that in each medial-lateral section, for every group and subgroup, the standard deviations generally increase as the horizontal distance from the tooth increases. There are several possible explanations for this trend. It could be related to the increasing mean vertical measurement. As the mean increases, an increase in standard deviation may be expected. Looking at the coefficient of variation, $S.D./\bar{X}$, the value is high near the cusp tip and actually decreases from 3.0 mm from the cusp tip on. An alternative explanation is that the error of the measurement is compounded as the distance from the cusp tip increases. Further investigation would be required to form any conclusions regarding

the reason for this effect.

Although the standard deviation is smaller on and near the tooth, the mean is also smaller. Assuming a normal distribution, the 95% confidence limits for the second bicuspid at a distance of 1.5 mm from the cusp, for example, are 1.29 mm to 7.93 mm. It is interesting to note that the mean bracket location was found to be at a horizontal distance of 1.57 mm from the cusp with a range of only 1.90 mm to 4.22 mm. This measurement came from the same sample and is in approximately the same location.

Each of the medial-lateral sections has also been plotted to aid in visualization of the numerical data and can be found in the Appendix. The plots are symmetrical plots of the combined sample (40 teeth). The points near the midline which represent decreased sample size have been noted and slight deviations from a smooth curve are seen as a result. The maxillary first bicuspid has also been plotted to show a comparison of right and left sides as well as male and female. This tooth was chosen because it showed the most variation between groups when the difference was expressed as a percentage of the combined sample mean.

Looking at right to left differences in the tables, the right vertical measurements are almost universally greater, indicating a steeper slope of the vault on the right side. The smallest right to left difference is found in the second molar region. The midline is located closer to the right in every section. This would explain the steeper slope on the right side. However, the standard deviation in the midline is generally

greater than the side to side difference. In the plot of right and left sides of the first bicuspid, the midline deviation and the steeper slope on the right are apparent but not remarkable.

Male and female differences are more complex. Vault height and vertical measurements are greater in the males for the first and second molars and male-female difference is greatest in these two sections. Dominance in vertical measurements is variable in the second bicuspid with a slightly greater male vault height. Vault height and vertical measurements are slightly greater in the females for the first bicuspid and cuspid. The plot of male and female means for the first bicuspid shows a steeper slope in the female with little difference in vault height when compared to the male. Differences are again not remarkable.

Looking at the symmetrical plots for the combined sample, it can be seen that a tangent along the side of the vault from the bracket becomes steeper from the cuspid to first molar and then decreases at the second molar due in part to a somewhat bulbous alveolus in the area of the second molar.

Table 11 summarizes the vertical measurements for the combined sample. It is of interest to note that the standard deviation is not directly correlated with increasing value of the vertical measurement at 12.0 mm from the cusp tip. The largest coefficient of variation is found in the cuspid region. The variation in the cuspid diagonal section is most likely due, in part, to the difficulty in orienting the template in recording palatal contour in this section.

Diagonal Sections

Measurements for the diagonal sections at the maxillary cuspids are presented in Table 2 in the same manner as described above for the medial-lateral sections.

In examining the data, it should be noted that the "horizontal" measurements do not cross the arch to the contralateral tooth, but are oriented from the cusp tip on each side to the intersection of the midpalatal raphe with the line joining the right and left bicuspids. The bracket is actually found on this section rather than on the medial-lateral section at the cuspid due to the inclination and orientation of the tooth in the arch form. This gingival margin location is also more meaningful because it falls along the long axis of the crown while the gingival margin found in Table 3 does not.

The combined sample has been plotted and appears in the Appendix. The numerical data also appears in Table 11. As noted above, the largest coefficient of variation was found in this section. This is attributed, in part to difficulty in orienting the template while recording these measurements.

In-Out

Measurements of in-out for each two-tooth segment are found in Table 8. As previously explained, measurements were obtained by subtracting the measured value for the distal tooth from the measured value for the mesial tooth. Negative values, therefore indicate a step in the lingual direction, while positive values indicate steps in the buccal direction. The upper portion of the table contains the data for the upper arch, while the lower

portion contains the data for the lower arch. All measurements were made to the nearest tenth of a millimeter.

Due to the small means of these measurements, particularly between the molars and bicuspid, the standard deviation is, at times, larger than the mean. Small means in the molar and bicuspid regions are expected since the buccal-lingual thickness of the teeth is very similar. That is why a step in the lingual arch wire is not usually required in these locations. The in-out between the cuspid and bicuspid, in particular, and also between the second bicuspid and first molar are very important, however. Looking at the step between the maxillary cuspid and first bicuspid, the range for the 95% confidence limits is -4.51 mm to -1.41 mm. Between the second bicuspid and first molar, this range is -2.79 mm to -0.21 mm. Similarly in the lower arch the range is -2.82 mm to -0.58 mm in the cuspid-bicuspid step, and -2.99 mm to -0.41 mm in the bicuspid-molar step.

Interbracket Distance

Table 9 contains the means and standard deviations of the interbracket distances for each two-tooth segment in the same manner as presented for in-out measurements. The distances have been recorded as the shortest distance between the centers of the beads on the corresponding teeth. All measurements were made to the nearest tenth of a millimeter.

The major difference in interbracket difference on the lingual as compared to the buccal is between the anterior teeth. This was not measured in the present investigation. The interbracket distance between the bicuspid is very similar on

the lingual as compared to the buccal. The primary figures to look at are, then the cuspid to bicuspid distance and molar to bicuspid distance. A range for 95% confidence limits in the cuspid-bicuspid region would be 5.35 mm to 8.65 mm in the upper arch and 5.13 mm to 8.27 mm in the lower arch. Similarly, in the bicuspid-molar region the ranges would be 5.77 mm to 8.83 mm in the upper arch and 6.96 mm to 10.44 mm in the lower arch.

Arch Width at the Bracket Level

Measurements of arch width were made across the arch at the level of the bracket for the cuspids and each of the posterior teeth. Measurements were made to the nearest tenth of a millimeter. Table 10 contains the means and standard deviations at each cross section for males, females and for the total sample. It also lists the maximum and minimum value for each cross section.

Mean arch width is surprisingly similar in male versus female patients. There is only about a 1mm difference in each cross section. It should be noted that, although the standard deviations are small, there is an appreciable range of arch widths in the combined sample. The largest range, in the second molar cross section, is 1.0 cm.

DISCUSSION

Throughout the literature, there has been a constant search for a means of describing arch form and palatal vault form. In addition to variation within the population, one problem in doing so is the fact that the dental complex, like the rest of the body is not symmetrical. Right to left differences have been noted in the literature, as well as differences in size between the sexes. The purpose of this study was not to find conclusive evidence for or against these theories, but rather to describe lingual anatomy in some way which might be useful to the orthodontist in his attempt to improve lingual orthodontic treatment. However, trends noted in the data have been pointed out.

The data has been presented numerically in Tables 2-10. Graphical representations have been included in the Appendix to aid in visualization of the numerical data, including comparisons between the sexes and asymmetries in vault form found in the sample.

It is interesting to note that the midline is located closer to the right side in every mean determination in every section and every group or subgroup, although the standard deviation is generally greater than the side to side difference. A left side dominance in maxillary dental and apical base midline was also noted by Ritucci and Burstone in a 1981 thesis at the University of Connecticut entitled: "Use of the Submental Vertex³⁷ Radiograph in the Assessment of Asymmetry." Proffit, et al also found tongue pressure to be greater on the left side during swallowing in both children and adults.

Male and female measurements were not as different as might be expected. Vault height and vertical measurements were greater for males in the posterior sections and greater for females in the anterior sections.

Since the right-left and male-female differences are not great based upon this relatively small sample, further discussion will be based upon the combined sample, described in Table 11 for the palatal contour measurements, and in the appropriate columns of Tables 8-10 for the in-out, interbracket distances, and arch width measurements.

In the design of any orthodontic appliance, an understanding of the required force system, as well as its relationship to bioengineering principles can be essential. In designing a space closing device for lingual orthodontic treatment, it is important to note the difference in the relationship of the device to the surrounding anatomy. On the buccal, the device would be oriented approximately in the y-z plane. It can be seen from the plots of mean data of palatal contour that this is not the case on the lingual. Components of the force system must be considered in the x-z plane as well. The plots may be helpful in determining the angle of the space closing device to the bracket of the appropriate tooth. If the clinician wishes to design a 7 mm high spring, for example, he may wish to find the horizontal distance from the bracket necessary to achieve this height and use this information to determine the angle of the device to the bracket. For the first molar, looking at the plot, this distance would be 3 mm. from the bracket or 5.6 mm from the cusp tip. However, the

range for 95% confidence limits would be about 1.2 mm to 4.9 mm from the bracket. It is desirable to keep the appliance as close to the tissue as possible when inserting it in a patient's mouth. However, a horizontal change of 3.7 mm would result in a significant change in the angle of the spring to the bracket. This would, in turn, change the force system delivered to the teeth. So, although this mean data serves as a starting point in appliance design, it appears that it will be necessary to diversify designs to fit different groups of individuals.

Similarly, in measurements of in-out found in Table 8, the standard deviations resulted in ranges which were too great to be universally applicable. A very important area to be evaluated in lingual orthodontic treatment is the maxillary cuspid and its position relative to the first bicuspid. Not only is the step between these teeth important for arch wire fabrication and determination of the required force system, but the situation is complicated by palatal vault inclination, interbracket distance and interference with the lower occlusion. Unfortunately, the range for this in-out measurement ± 1.96 S.D. is from -1.41 mm to -4.51 mm. This is similar to the measurement given by Smith, et al⁴⁶ of 2-4 mm. However, it is again too variable for highly accurate force determination for the population as a whole. Again, different configurations may be required for application to various groups of individuals.

Ranges for interbracket distances were also found to be greater than 3 mm which is quite large for clinical applications. Similarly, arch width varied by as much as 10 mm in the second

molar region.

Although the data compiled, as a whole, shows too much variation for precise determination of an optimal force system for universal use, a greater understanding of lingual anatomy and its relationship to lingual bracket position has been gained. Although the use of this information in appliance design may not be applicable to every individual, it would certainly be more applicable than labial mechanics and should therefore yield better treatment results.

SUMMARY

One difficulty encountered when the clinician transfers his techniques for buccal orthodontic treatment to the lingual surfaces of the teeth is that the geometry of the attachments and of the surrounding anatomy is entirely different, particularly in the palatal arch. This geometry is not yet well understood.

A study of palatal vault contour and lingual interdental relationships was conducted on study models of a sample of twenty adults with no history of orthodontic treatment and reasonably well-aligned teeth. Data describing palatal contour was generated in medial-lateral sections at each tooth from cuspid to second molar using an adjustable carpenter's template. Lingual bracket position as well as the location of the gingival margin was determined in each section. Occlusal photos were used to measure lingual arch width, in-out and interbracket distance for each two-tooth segment.

Means and standard deviations were calculated for all measurements. Variation was found to be too great for universal application to all patients. However mean plots of palatal contour in each section including the position of the bracket and gingival margin may be a useful tool in determining the mean relationships of the attachments to the surrounding anatomy. This, in turn, would define the orientation of a space closing device to the bracket which is essential for a biomechanical approach to lingual appliance design.

A P P E N D I X

F I G U R E S

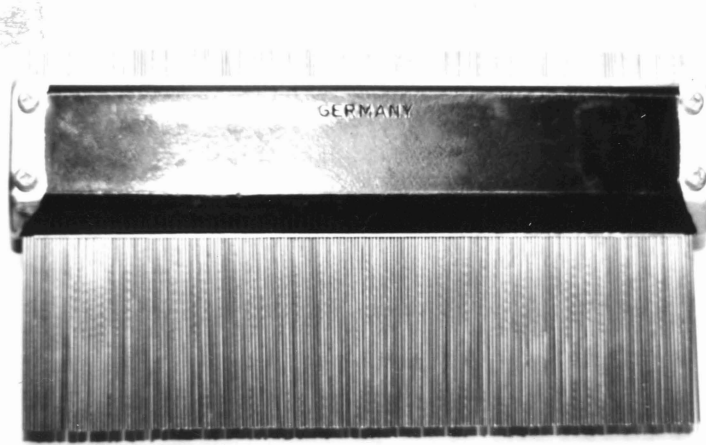


FIGURE 1. Adjustable carpenter's template used to register palatal contour of study models.

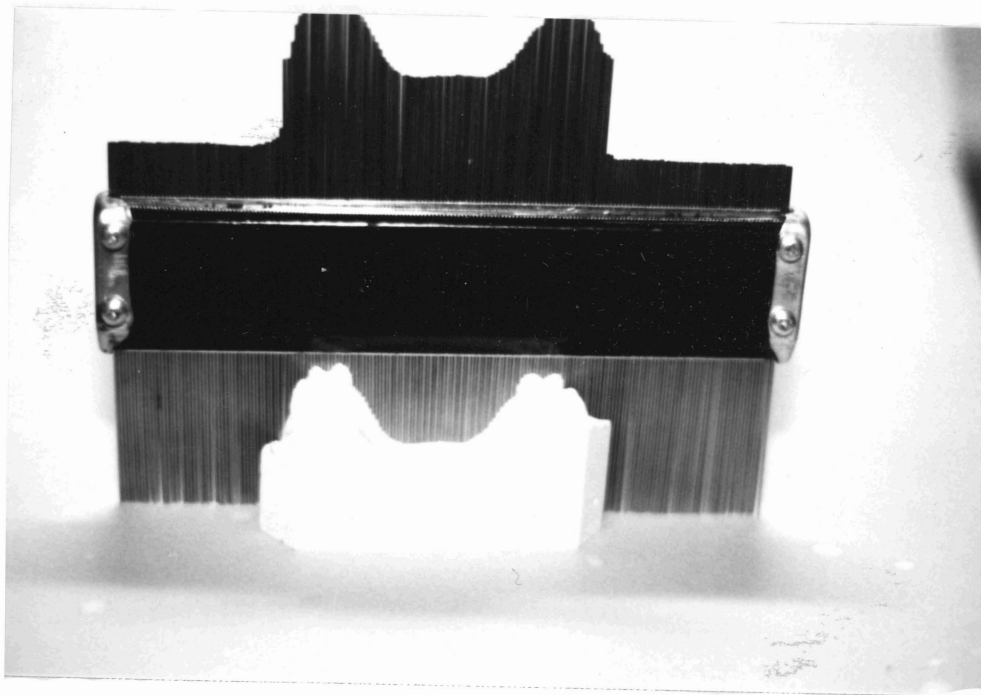


FIGURE 2. Template adapted to surface of model in first molar region.

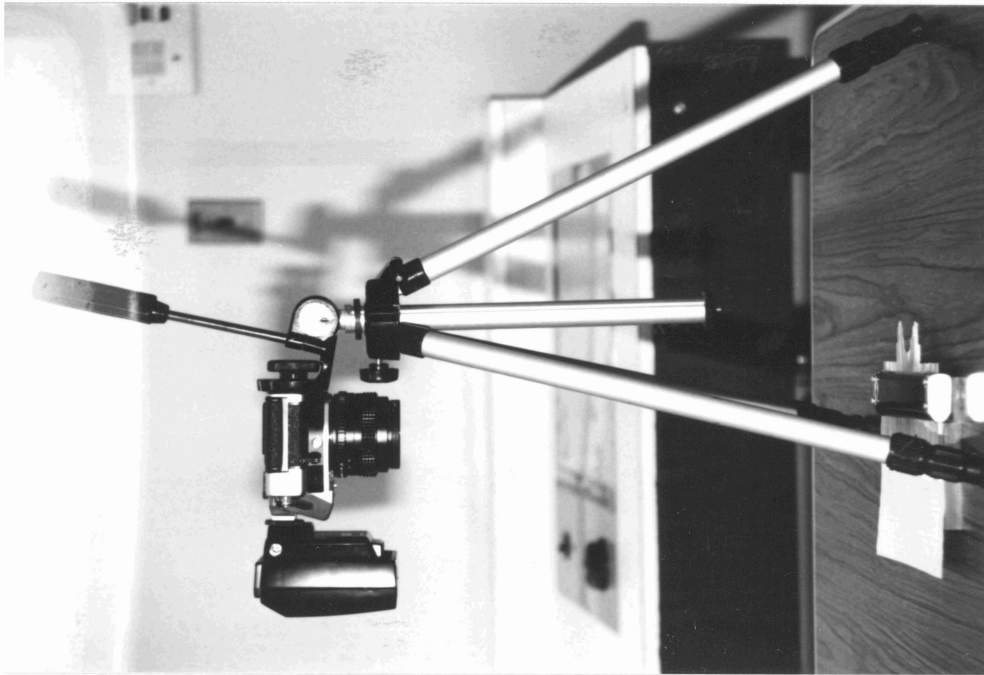


FIGURE 3. Tripod set-up for template photographs.

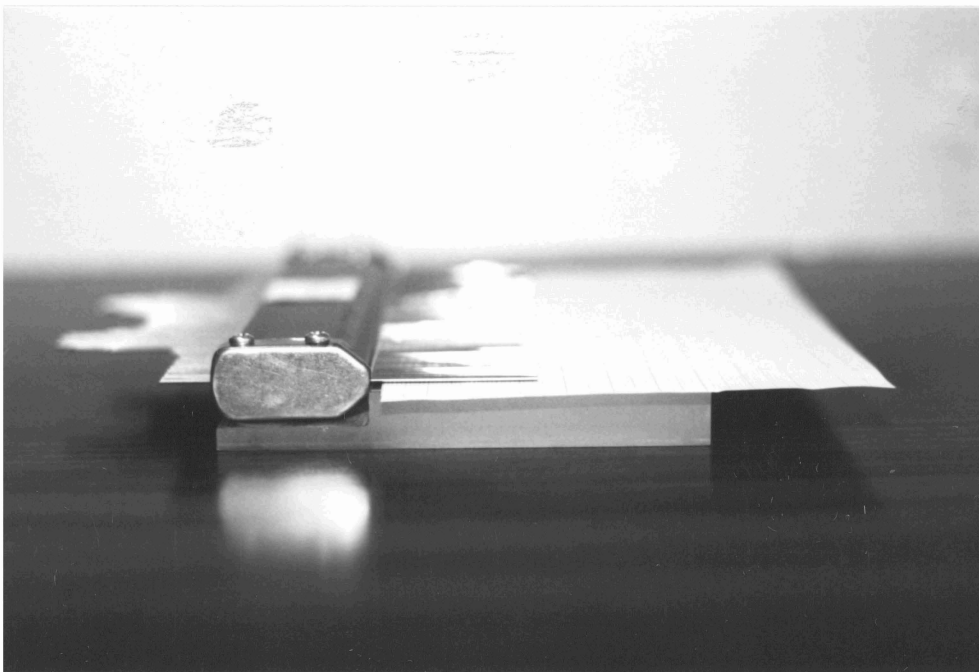


FIGURE 4. Plexiglass holder for close approximation of template with graph paper.

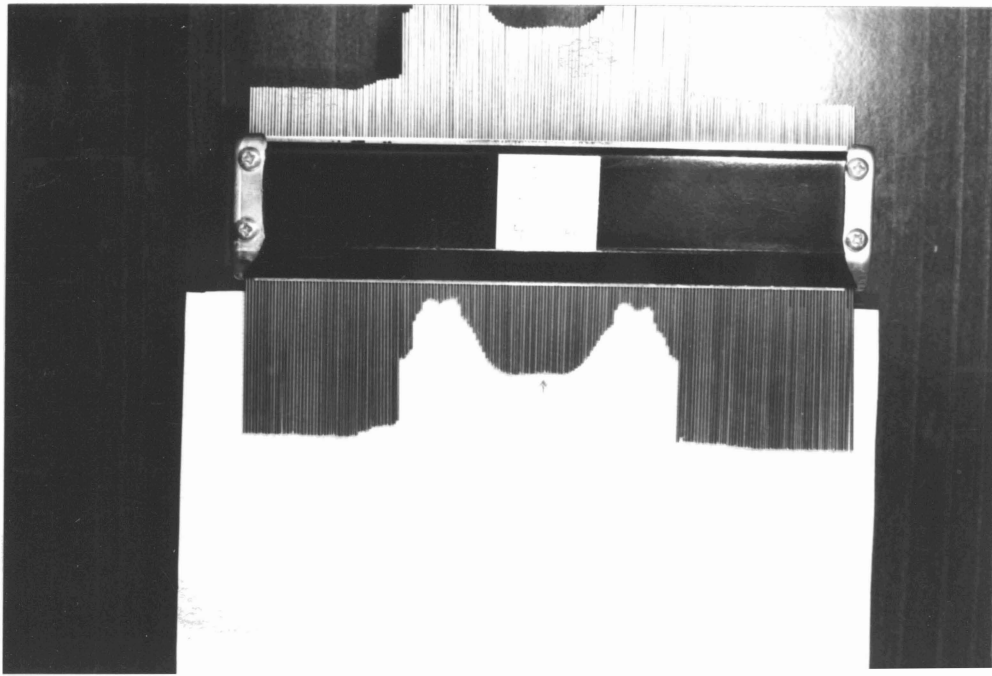


FIGURE 5. Example of template photograph used in assessing palatal contour.

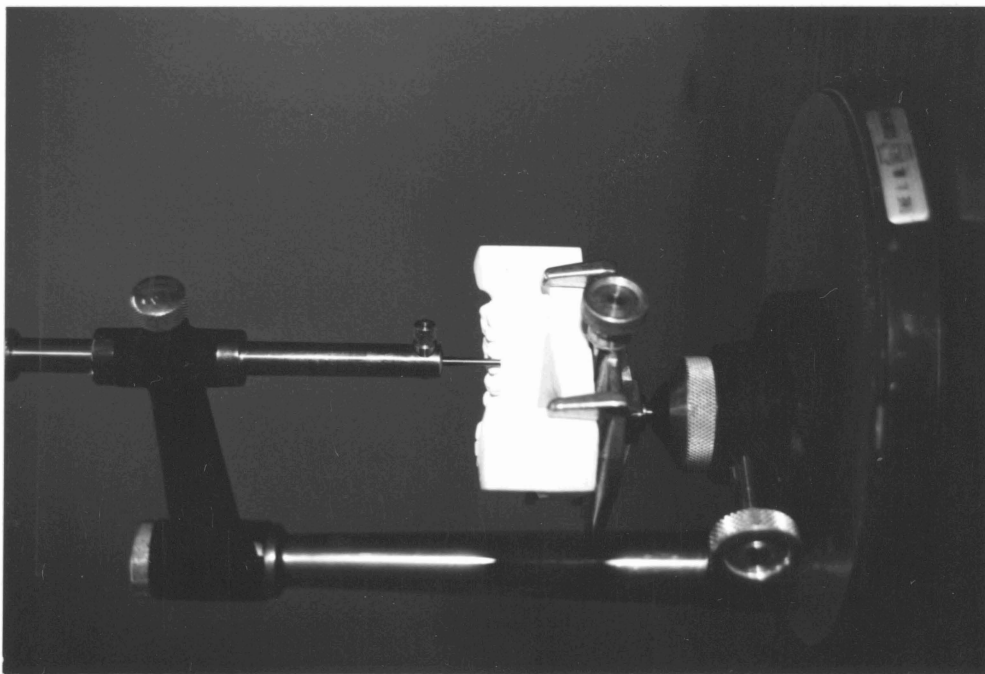


FIGURE 6. Surveying of model for lingual bead placement.

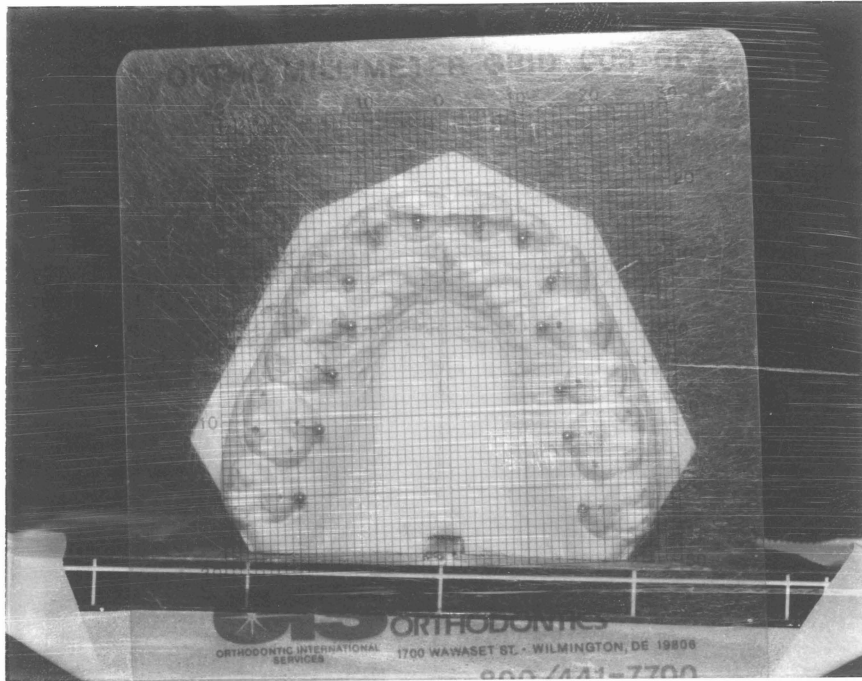


FIGURE 7. Sample occlusal photograph used to determine interbracket distances, in-out and lingual arch widths.

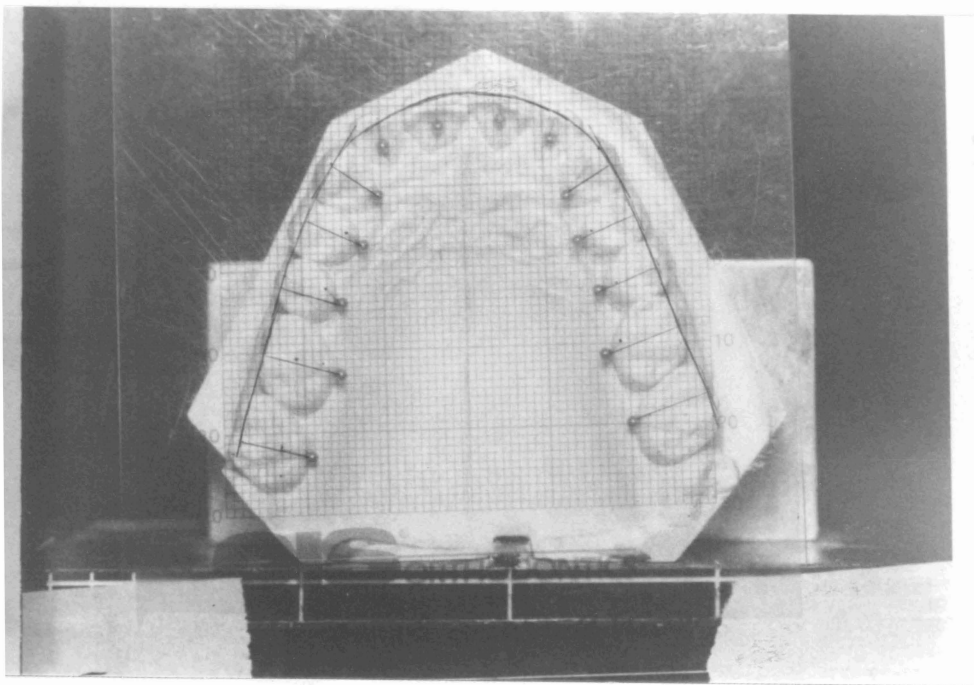


FIGURE 8. Constructed tangents and perpendiculars for in-out measurement.

TABLE 1: Description of sample by occlusion and age. (Note: All odd-numbered patients are male; all even-numbered patients are female.)

TABLE 1: Description of Sample

Pt.	Right	Left	Overjet	Overbite	Midline
1	1.5mm C1 II	C1 I	1mm	6mm(67%)	.5mm Rt
2	1.5mm C1 II	2mm C1 II	1mm	4mm(60%)	1mm Lt
3	2mm C1 II	2mm C1 II	2mm	2mm(25%)	
4	C1 I	C1 I	.5mm	1.5mm(15%)	.5mm Lt
5	C1 I	C1 I	.5mm	1mm(10%)	
6	.5mm C1 II	.5mm C1 II	1mm	4mm(67%)	1mm Rt
7	1.5mm C1 II	1.5mm C1 II	1mm	3mm(35%)	.5mm Lt
8	C1 I	1mm C1 III	1mm	2mm(25%)	
9	2mm C1 III	C1 I	1mm	2mm(22%)	1mm Lt
10	1mm C1 II	C1 I	1.5mm	3mm(30%)	
11	1mm C1 III	C1 I	2mm	2mm(30%)	2.5mm Lt
12	1.5mm C1 II	1.5mm C1 II	1mm	2.5mm(40%)	
13	3.5mm C1 II	5mm C1 II	4mm	3mm(35%)	1.5mm Lt
14	2mm C1 II	C1 I	1.5mm	4mm(45%)	1mm Rt
15	1mm C1 II	C1 I	3mm	4.5mm(55%)	1mm Rt
16	C1 I	1mm C1 II	1.5mm	4.5mm(50%)	
17	C1 I	1mm C1 II	.5mm	2mm(20%)	1mm Lt
18	C1 I	1mm C1 II	1.5mm	1.5mm(20%)	1.5mm Lt
19	3mm C1 III	2mm C1 III	.5mm	2mm(30%)	1.5mm Lt
20	2mm C1 II	C1 I	1.5mm	4mm(40%)	1mm Rt

	<u>Mean Age</u>	<u>Age Range</u>
Male	29:9	24:4 - 43:7
Female	27:3	21:0 - 34:6
Combined	28:6	21:0 - 43:7

TABLE 2: Diagonal section at maxillary cuspid. Mean vertical measurements in millimeters by subgroup. Mean location of midline, bracket, and gingival margin.

TABLE 2

MAXILIARY USPID: Diagonal section

VERTICAL	Male				Female				Male/Female				Male				Female				Combined			
	Right		Left		Right		Left		Right		Left		Right/Left		Right/Left		Male/Left		Male/Right		Female/Left		Female/Right	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
HORIZ	.97	.34	.95	.44	1.15	.64	.97	.42	1.06	.51	.96	.42	.96	.38	1.06	.53	1.01	.46	1.01	.46	1.01	.46	1.01	.46
1.50	3.25	.83	3.02	.76	3.22	1.28	3.00	.49	3.24	1.05	3.01	.62	3.14	.78	3.11	.95	3.13	.86	3.13	.86	3.13	.86	3.13	.86
3.00	4.82	1.15	4.57	1.03	5.02	1.68	4.40	.73	4.92	1.40	4.49	.87	4.70	1.07	4.71	1.30	4.71	1.17	4.71	1.17	4.71	1.17	4.71	1.17
4.50	6.52	1.17	6.07	1.26	6.60	1.79	6.30	1.32	6.56	1.47	6.19	1.26	6.30	1.21	6.45	1.54	6.38	1.37	6.38	1.37	6.38	1.37	6.38	1.37
6.00	7.63	1.10	7.13	1.33	7.72	2.36	7.32	1.63	7.67	1.79	7.22	1.45	7.38	1.22	7.52	1.98	7.45	1.63	7.45	1.63	7.45	1.63	7.45	1.63
7.50	8.47	1.36	8.10	1.65	9.35	3.41	8.88	2.05	8.91	2.56	8.49	1.85	8.29	1.48	9.11	2.75	8.70	2.22	8.70	2.22	8.70	2.22	8.70	2.22
9.00	9.67	1.81	9.02	2.42	11.88	3.50	10.30	2.44	10.77	2.94	9.66	2.45	9.35	2.11	11.09	3.05	10.22	2.73	10.22	2.73	10.22	2.73	10.22	2.73
10.50	11.65	2.20	10.52	2.84	13.67	3.37	12.75	2.31	12.66	2.96	11.64	2.77	11.09	2.54	13.21	2.85	12.15	2.88	12.15	2.88	12.15	2.88	12.15	2.88

	Male				Female				Male/Female				Male				Female				Combined			
	Right	SD	Left	SD	Right	SD	Left	SD	Right	SD	Left	SD	Right/Left	SD	Right/Left	SD	Right/Left	SD	Right/Left	SD	Male/Female	SD		
MIDDLE																								
Horiz.	17.55	1.33	18.38	1.47	16.50	1.32	17.70	1.33	17.02	1.40	18.04	1.41	17.96	1.43	17.10	1.43	17.53	1.48						
Vert.	16.38	2.61	16.15	2.72	16.85	2.69	16.90	2.60	16.61	2.59	16.52	2.62	16.26	2.60	16.88	2.57	16.57	2.57						
BRACKET																								
Horiz.	3.66	.61	3.74	.58	3.51	.57	3.57	.42	3.58	.58	3.65	.50	3.70	.58	3.54	.49	3.62	.54						
Vert.	3.82	.86	3.65	.59	3.70	.85	3.67	.66	3.76	.83	3.66	.61	3.74	.72	3.69	.74	3.71	.72						
GING. MARG.																								
Horiz.	5.47	.36	5.63	.53	5.25	.61	5.25	.50	5.36	.50	5.44	.54	5.55	.45	5.25	.54	5.40	.52						
Vert.	6.22	1.08	5.95	.96	6.07	1.48	5.80	1.31	6.15	1.26	5.88	1.12	6.09	1.00	5.94	1.37	6.01	1.19						

TABLE 3: Medial-lateral section at maxillary cuspid. Mean vertical measurements in millimeters by subgroup. Mean location of midline and gingival margin. Bracket does fall on this section due to orientation of tooth in arch (see Table 2 for bracket location).

TABLE 4: Medial-lateral section at maxillary first bicuspid.
Mean vertical measurements in millimeters by subgroup.
Mean location of midline, bracket and gingival margin.

TABLE 4

MAXILIARY FIRST BICUSPID: Medial-lateral section

HORIZ	VERTICAL																	
	Male				Female				Male/Female				Combined					
	Right \bar{X}	Right SD	Left \bar{X}	Left SD	Right \bar{X}	Right SD	Left \bar{X}	Left SD	Right \bar{X}	Right SD	Left \bar{X}	Left SD	Right/Left \bar{X}	Right/Left SD	Right/Left \bar{X}	Right/Left SD		
1.50	4.38	2.16	3.72	1.94	4.50	1.94	3.75	2.12	4.44	2.00	3.74	1.98	4.05	2.03	4.13	2.02	4.09	2.00
3.00	7.07	1.42	6.70	.81	8.05	2.48	7.00	1.23	7.56	2.03	6.85	1.02	6.89	1.14	7.52	1.98	7.21	1.63
4.50	8.63	.97	8.55	.81	10.00	2.97	8.72	1.66	9.31	2.27	8.64	1.27	8.59	.87	9.36	2.43	8.97	1.85
6.00	10.63	1.70	9.85	1.36	12.40	2.73	10.63	1.43	11.51	2.39	10.24	1.42	10.24	1.55	11.51	2.31	10.88	2.04
7.50	12.57	2.03	11.32	1.39	14.27	2.86	13.00	1.75	13.42	2.57	12.16	1.76	11.95	1.81	13.64	2.40	12.79	2.27
9.00	13.80	2.21	12.88	1.45	15.20	2.71	14.25	1.76	14.50	2.51	13.56	1.72	13.34	1.88	14.72	2.28	14.03	2.18
10.50	14.72	2.43	13.95	1.93	15.52	2.44	15.02	1.94	15.13	2.41	14.49	1.96	14.34	2.17	15.27	2.16	14.81	2.19
12.00	15.25	2.68	14.67	1.94	15.95	2.42	15.65	2.32	15.60	2.51	15.16	2.14	14.96	2.30	15.80	2.31	15.38	2.31

	Male				Female				Male/Female				Male		Female				Combined	
	Right	SD	Left	SD	Right	SD	Left	SD	Right	SD	Left	SD	Right/Left	SD	Right/Left	SD	Male/Female	SD		
MIDDLE																				
Horiz.	13.65	1.05	15.30	1.70	12.97	1.00	14.17	1.56	13.31	1.06	14.74	1.69	14.47	1.62	13.57	1.42	14.02	1.57		
Vert.	15.72	2.50	15.72	2.50	15.88	2.33	15.88	2.33	15.80	2.35	15.80	2.35	15.72	2.43	15.88	2.27	15.80	2.32		
BRACKET																				
Horiz.	1.45	.27	1.38	.32	1.41	.36	1.36	.55	1.43	.31	1.37	.44	1.41	.29	1.38	.46	1.40	.38		
Vert.	2.75	.42	2.88	.43	3.00	.50	3.00	.53	2.88	.47	2.94	.47	2.81	.42	3.00	.50	2.91	.47		
GING. MARC.																				
Horiz.	1.80	.52	1.80	.39	1.65	.47	1.92	.54	1.72	.49	1.86	.46	1.80	.45	1.78	.51	1.79	.47		
Vert.	5.42	.83	5.20	.54	5.35	.90	5.28	.84	5.39	.90	5.28	.84	5.31	.69	5.32	.85	5.31	.76		

TABLE 5: Medial-lateral section at maxillary second bicuspid.
Mean vertical measurements in millimeters by subgroup.
Mean location of midline, bracket and gingival margin.

TABLE 5

MAXILLARY SECOND BICUSPID: Medial-1-lateral section

[illegible]

	Male				Female				Male/Female				Male		Female		Combined
	Right	SD	Left	SD	Right	SD	Left	SD	Right	SD	Left	SD	Right/Left	SD	Right/Left	SD	Male/Female
MIDDLE																	
Horiz.	16.72	1.73	17.25	.94	15.52	1.42	16.88	1.63	16.13	1.66	17.06	1.31	16.99	1.38	16.20	1.64	16.59
Vert.	20.38	2.06	20.38	2.06	19.00	2.37	19.00	2.37	19.69	2.27	19.69	2.27	20.38	2.00	19.00	2.31	19.69
BRACKET																	
Horiz.	1.58	.60	1.54	.30	1.44	.34	1.72	.55	1.51	.48	1.63	.44	1.56	.46	1.58	.47	1.57
Vert.	2.88	.48	3.02	.64	3.15	.63	3.17	.64	3.01	.56	3.10	.63	2.95	.55	3.16	.61	3.06
GING. MARG.																	
Horiz.	1.95	.88	1.95	.52	1.92	.40	2.02	.51	1.93	.68	1.99	.50	1.95	.71	1.97	.45	1.96
Vert.	5.42	1.23	5.52	1.15	5.25	.77	5.77	.98	5.34	1.01	5.65	1.05	5.47	1.16	5.53	.90	5.50

TABLE 6: Medial-lateral section at maxillary first molar. Mean
vertical measurements in millimeters by subgroup. Mean
location of midline, bracket and gingival margin.

TABLE 6

MAXILLARY FIRST MOLAR: Medial-lateral section

		VERTICAL																	
		Male			Female			Male/Female			Male		Female		Combined				
		Right	SD	\bar{x}	Left	SD	\bar{x}	Right	SD	\bar{x}	Left	SD	\bar{x}	Right/Left	SD	Right/Left	SD	Male/Female	SD
HORIZ	\bar{x}	1.22	.43	1.07	.41	1.05	.52	1.07	.72	1.14	.48	1.07	.57	1.15	.42	1.06	.61	1.11	.52
	SD	5.90	1.09	4.92	1.68	4.55	2.06	4.97	1.70	5.22	1.75	4.95	1.65	5.41	1.47	4.76	1.85	5.09	1.68
	\bar{x}	8.20	1.71	7.85	.95	7.97	2.37	7.45	.97	8.09	2.02	7.65	.96	8.02	1.36	7.71	1.78	7.87	1.57
	SD	12.07	2.33	11.25	1.56	10.90	2.54	10.27	1.51	11.49	2.45	10.76	1.57	11.66	1.98	10.59	2.06	11.13	2.06
	\bar{x}	7.50	2.41	14.25	1.39	13.72	2.19	13.05	1.72	14.29	2.31	13.65	1.64	14.55	1.94	13.39	1.95	13.97	2.01
	SD	9.00	2.98	16.70	1.96	16.00	1.73	15.17	2.02	16.60	2.45	15.94	2.10	16.95	2.47	15.59	1.89	16.27	2.27
	\bar{x}	10.50	3.08	18.63	2.20	17.60	1.71	16.95	1.90	18.42	2.57	17.79	2.18	18.94	2.63	17.27	1.79	18.11	2.37
	SD	12.00	2.83	19.97	2.01	18.63	1.66	18.07	1.83	19.65	2.49	19.02	2.11	20.32	2.42	18.35	1.72	19.34	2.30
		Male			Female			Male/Female			Male		Female		Combined				
		Right	SD	\bar{x}	Left	SD	\bar{x}	Right	SD	\bar{x}	Left	SD	\bar{x}	Right/Left	SD	Right/Left	SD	Male/Female	SD
MIDLINE	\bar{x}	18.15	1.11	19.50	1.00	18.00	1.19	18.82	1.52	18.08	1.12	19.16	1.30	18.82	1.24	18.43	1.40	18.63	1.32
	SD	22.10	2.25	22.10	2.25	18.56	2.39	18.82	2.41	20.42	2.89	20.46	2.82	22.10	2.19	18.70	2.33	20.44	2.82
		BRACKET			BRACKET			BRACKET			BRACKET			BRACKET					
HORIZ.	\bar{x}	2.54	.28	2.58	.43	2.57	.52	2.61	.60	2.55	.40	2.59	.51	2.56	.35	2.59	.54	2.57	.45
	SD	3.45	.51	3.27	.61	2.95	.71	3.13	.79	3.20	.65	3.20	.69	3.36	.55	3.04	.74	3.20	.66
		GING. MARG.			GING. MARG.			GING. MARG.			GING. MARG.			GING. MARG.					
HORIZ.	\bar{x}	3.07	.24	3.15	.59	3.07	.55	3.00	.50	3.07	.41	3.07	.54	3.11	.44	3.04	.51	3.07	.47
	SD	6.22	.84	6.10	.97	5.35	1.31	5.75	.60	5.79	1.16	5.92	.80	6.16	.88	5.55	1.02	5.86	.99

TABLE 7: Medial-lateral section at maxillary second molar. Mean
vertical measurements in millimeters by subgroup. Mean
location of midline, bracket and gingival margin.

TABLE 7

MAXILLARY SECOND MOLAR: Medial-lateral section

[illegible]

	Male				Female				Male/Female				Male				Female				Combined			
	Right	SD	Left	SD	Right	SD	Left	SD	Right	SD	Left	SD	Right/Left	SD	Right/Left	SD	Right/Left	SD	Right/Left	SD	Male/Female	SD		
<u>MDLT, I.N.E.</u>																								
Horiz.	21.00	2.03	22.72	1.33	20.40	1.11	21.90	1.31	20.70	1.11	21.90	1.31	21.86	1.89	21.15	1.41	21.51	1.68						
Vert.	20.60	2.78	20.60	2.78	16.65	2.58	16.65	2.58	18.63	3.31	18.63	3.31	20.60	2.71	16.65	2.51	18.63	3.26						
<u>BRACKET</u>																								
Horiz.	2.43	.44	2.33	.60	2.39	.52	2.46	.37	2.41	.47	2.39	.49	2.38	.51	2.42	.44	2.40	.47						
Vert.	2.47	.62	2.55	1.18	2.25	.63	2.20	.52	2.36	.62	2.38	.91	2.51	.92	2.22	.57	2.37	.77						
<u>GING. MARG.</u>																								
Horiz.	3.45	.52	3.22	.71	3.30	.52	3.52	.36	3.38	.52	3.38	.57	3.34	.62	3.41	.45	3.38	.54						
Vert.	4.65	1.56	4.45	1.40	4.02	1.06	4.57	.76	4.34	1.34	4.51	1.10	4.55	1.45	4.30	.94	4.42	1.21						

TABLE 8: Mean in-out measurement in millimeters for each two-tooth segment, cuspid to second molar, for each subgroup.

IN-OUT

LOCATION	Male				Female				Male/Female		Male		Female		Combined		
	Right \bar{X}	Right SD	Left \bar{X}	Left SD	Right \bar{X}	Right SD	Left \bar{X}	Left SD	Right \bar{X}	Right/Left SD	Left \bar{X}	Left SD	Right/Left \bar{X}	Right/Left SD	Male/Female \bar{X}	Male/Female SD	
3-4	-3.2	.86	-2.6	.79	-3.0	.58	-3.0	.51	.72	-2.8	.88	-2.9	.85	-3.0	.74	-2.96	.79
4-5	-.3	.36	-.4	.44	-.3	.59	-.4	.78	.47	-.4	.63	-.4	.39	-.4	.68	-.4	.55
5-6	-1.6	.59	-1.7	.58	-1.3	.62	-1.2	.77	.57	-1.5	.73	-1.7	.57	-1.2	.68	-1.5	.66
6-7	.2	1.05	.3	.62	.5	.69	.3	.65	.86	.3	.60	.3	.84	.4	.66	.3	.75

LOCATION	Male				Female				Male/Female				Male		Female		Combined	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
3-4	-1.7	.74	-1.7	.87	-1.5	.53	-2.0	.51	-1.6	.62	-1.8	.73	-1.7	.78	-1.7	.57	-1.7	.57
4-5	-1.0	.44	-.8	.74	-1.2	.68	-.7	.32	-1.1	.57	-.7	.61	-.9	.61	-.8	.66	-.9	.62
5-6	-1.8	.68	-1.6	.74	-1.5	.57	-1.7	.86	-1.7	.65	-1.8	.66	-1.7	.71	-1.6	.64	-1.7	.66
6-7	.2	.52	.4	.29	.4	.47	.4	.52	.3	.54	.4	.42	.3	.42	.3	.54	.3	.48

TABLE 9: Mean interbracket distance in millimeters for each two-tooth segment, cuspid to second molar, for each subgroup.

TABLE 9

INTERBRACKET DISTANCEUPPER ARCH

LOCATION	Male				Female				Male/Female		Male		Female		Combined			
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	Right/Left	SD	Right/Left	SD	Male/Female	SD		
3-4	7.5	.74	7.2	.73	6.8	.75	6.6	.97	7.1	.81	6.9	.88	7.3	.74	6.7	.86	7.0	.84
4-5	7.4	.37	7.2	.66	7.0	.46	7.2	.58	7.2	.45	7.2	.61	7.2	.53	7.1	.53	7.2	.53
5-6	7.5	1.01	7.4	.82	7.2	.62	7.0	.63	7.3	.82	7.2	.74	7.3	.90	7.2	.64	7.3	.78
6-7	10.5	.95	10.7	1.04	10.0	.87	10.1	.71	10.2	.93	10.4	.92	10.6	.97	10.1	.79	10.3	.91

LOWER ARCH

LOCATION	Male				Female				Male/Female		Male		Female		Combined			
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	Right/Left	SD	Right/Left	SD	Male/Female	SD		
3-4	6.7	.92	7.0	.85	6.7	.76	6.4	.68	6.7	.82	6.7	.81	6.8	.92	6.6	.67	6.7	.8
4-5	6.5	.90	6.5	.96	5.8	.71	6.2	.77	6.2	.86	6.4	.86	6.4	.99	6.1	.69	6.3	.86
5-6	9.0	.75	8.9	.93	8.5	.82	8.5	1.07	8.7	.81	8.7	1.00	8.7	.65	8.7	1.09	8.7	.89
6-7	10.8	.93	11.1	.88	10.2	.69	10.1	1.01	10.5	.85	10.6	1.05	10.9	.91	10.1	.84	10.5	.95

TABLE 10: Mean arch width at bracket level in millimeters for each subgroup. Measured across arch at teeth indicated.

TABLE 10

ARCH WIDTH AT BRACKET LEVELUPPER ARCH

LOCATION	Male		Female		Combined		Minimum	Maximum
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD		
3-3	28.6	2.0	27.0	2.7	27.8	2.4	23.4	31.2
4-4	27.5	1.7	26.5	1.8	27.0	1.8	23.7	29.6
5-5	32.6	1.8	31.5	1.5	32.1	1.7	29.0	35.1
6-6	34.8	1.2	34.0	1.7	34.8	1.5	32.1	37.2
7-7	41.4	3.0	40.5	1.9	40.9	2.5	35.7	45.7

LOWER ARCH

LOCATION	Male		Female		Combined		Minimum	Maximum
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD		
3-3	22.3	1.7	21.1	1.9	21.7	1.9	17.9	25.5
4-4	25.5	1.7	25.2	1.7	25.4	1.6	22.3	27.6
5-5	29.0	2.3	27.9	1.5	28.5	2.0	24.8	32.1
6-6	32.5	2.5	31.7	1.3	32.1	2.0	28.5	36.4
7-7	39.4	3.5	38.6	1.8	39.0	2.7	34.3	43.8

TABLE 11: Summary of combined sample data by tooth. All measurements in millimeters.

TABLE 11

SUMMARY

VERTICAL

HORIZ	3 Diagonal		3		4		5		6		7	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
1.50	1.01	.46	1.06	.62	4.09	2.00	2.32	2.35	1.11	.52	1.14	1.08
3.00	3.13	.86	2.97	.85	7.21	1.63	6.94	1.72	5.09	1.68	3.50	1.43
4.50	4.71	1.17	4.84	1.08	8.97	1.85	9.55	2.02	7.87	1.57	5.20	1.55
6.00	6.38	1.37	5.63	1.15	10.88	2.04	11.93	2.24	11.13	2.06	7.11	2.15
7.50	7.45	1.63	6.17	1.31	12.79	2.27	14.72	2.46	13.97	2.01	9.91	2.42
9.00	8.70	2.22	6.58	1.42	14.03	2.18	16.92	2.37	16.27	2.27	12.27	2.21
10.50	10.22	2.73	7.06	1.52	14.81	2.19	18.25	2.24	18.11	2.37	14.22	1.98
12.00	12.15	2.88	7.30	1.64	15.38	2.31	19.02	2.16	19.34	2.30	15.66	2.21

	3 Diagonal		3		4		5		6		7	
	X	SD	X	SD	X	SD	X	SD	X	SD	X	SD
<u>MIDDLE</u>												
Horiz.	17.53	1.48	15.54	1.41	14.02	1.57	16.59	1.55	18.63	1.32	21.51	1.68
Vert.	16.57	2.57	7.14	1.95	15.80	2.32	19.69	2.24	20.44	2.82	18.63	3.26
<u>BRACKET</u>												
Horiz.	3.62	.54	N/A		1.40	.38	1.57	.46	2.57	.45	2.40	.47
Vert.	3.71	.72	N/A		2.91	.47	3.06	.59	3.20	.66	2.37	.77
<u>GING. MARC.</u>												
Horiz.	5.40	.52	4.50	.63	1.79	.47	1.96	.59	3.07	.47	3.38	.54
Vert.	6.01	1.19	5.11	1.07	5.31	.76	5.50	1.03	5.86	.99	4.42	1.21

PLOTS OF MEAN DATA:

1. Maxillary cuspid medial-lateral and diagonal. Combined sample only.
2. Maxillary first bicuspid. Combined sample, right/left comparison, male/female comparison.
3. Maxillary second bicuspid. Combined sample only.
4. Maxillary first molar. Combined sample only.
5. Maxillary second molar. Combined sample only.

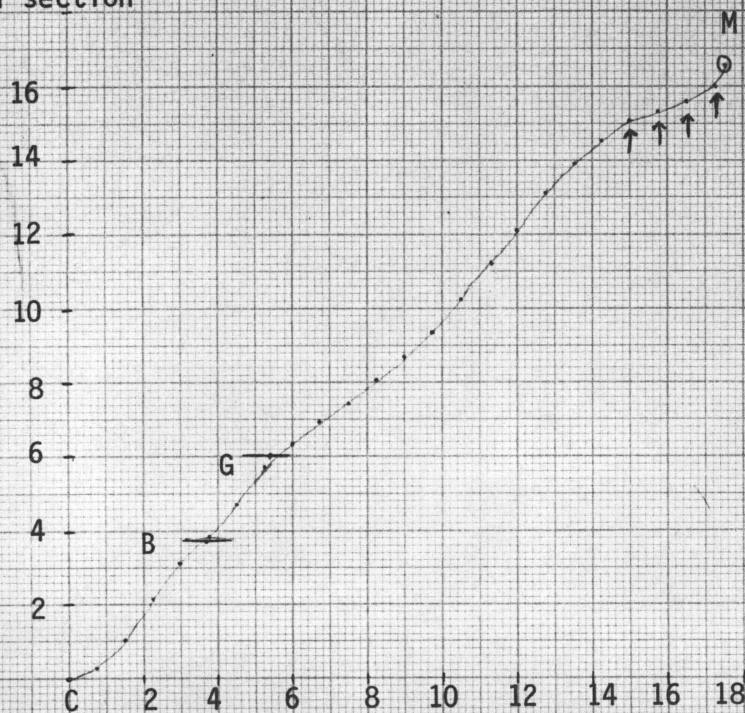
Maxillary Cuspid

All measurements in millimeters.
C=cusp tip, M=midline, G=gingival margin,
B=bracket, . =sample size decreased
↑

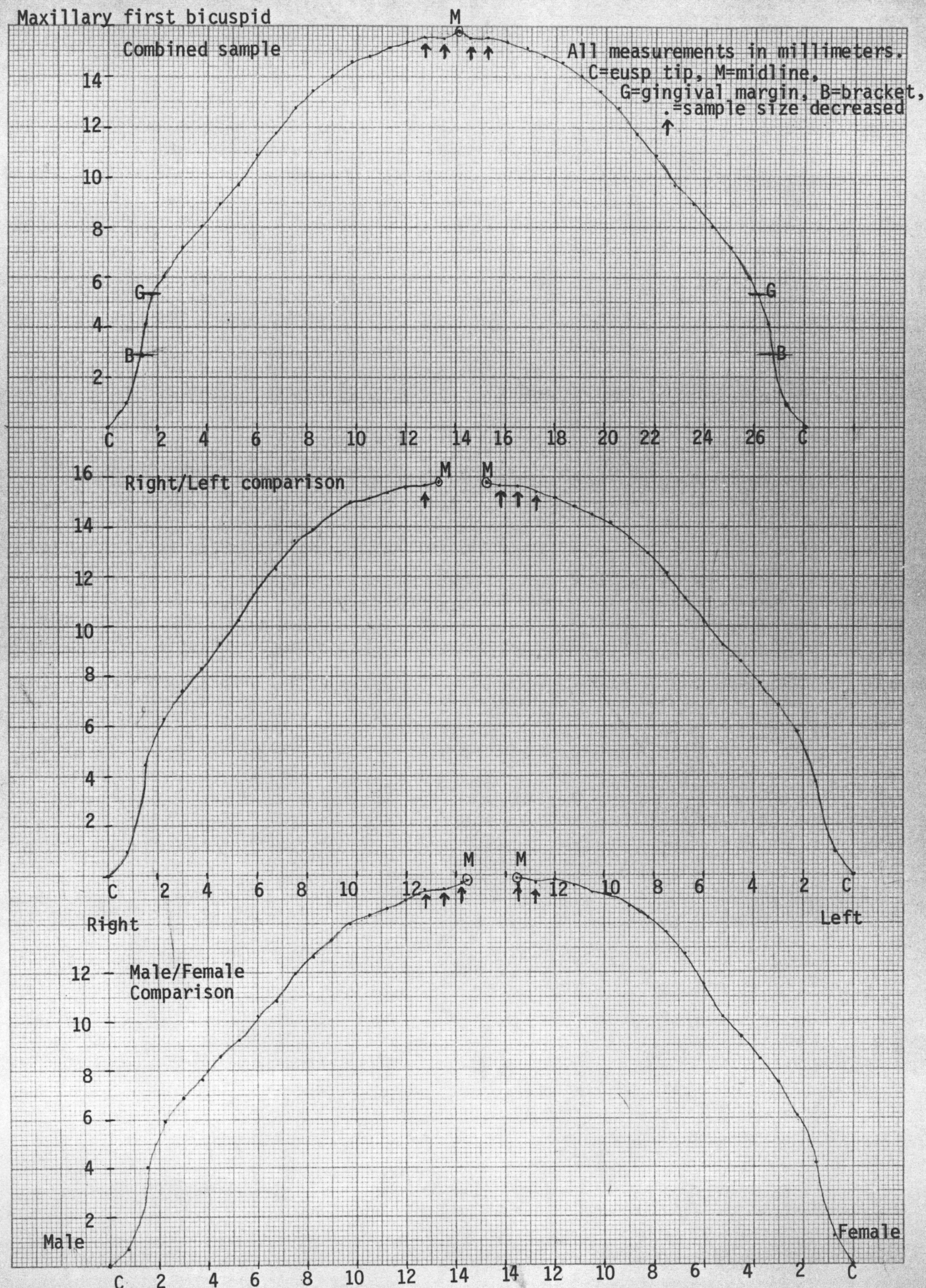
Medial-lateral section



Diagonal section

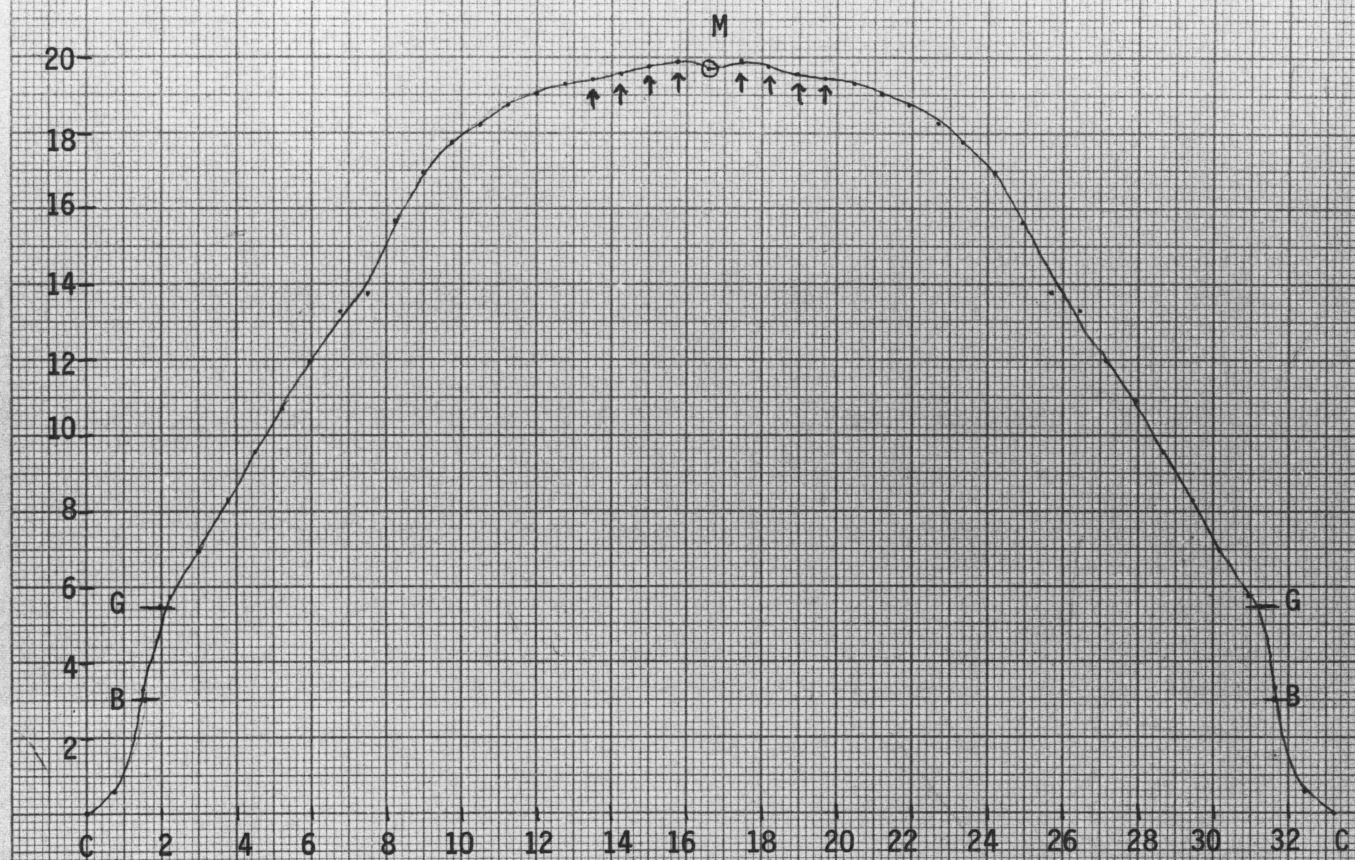


Maxillary first bicuspid



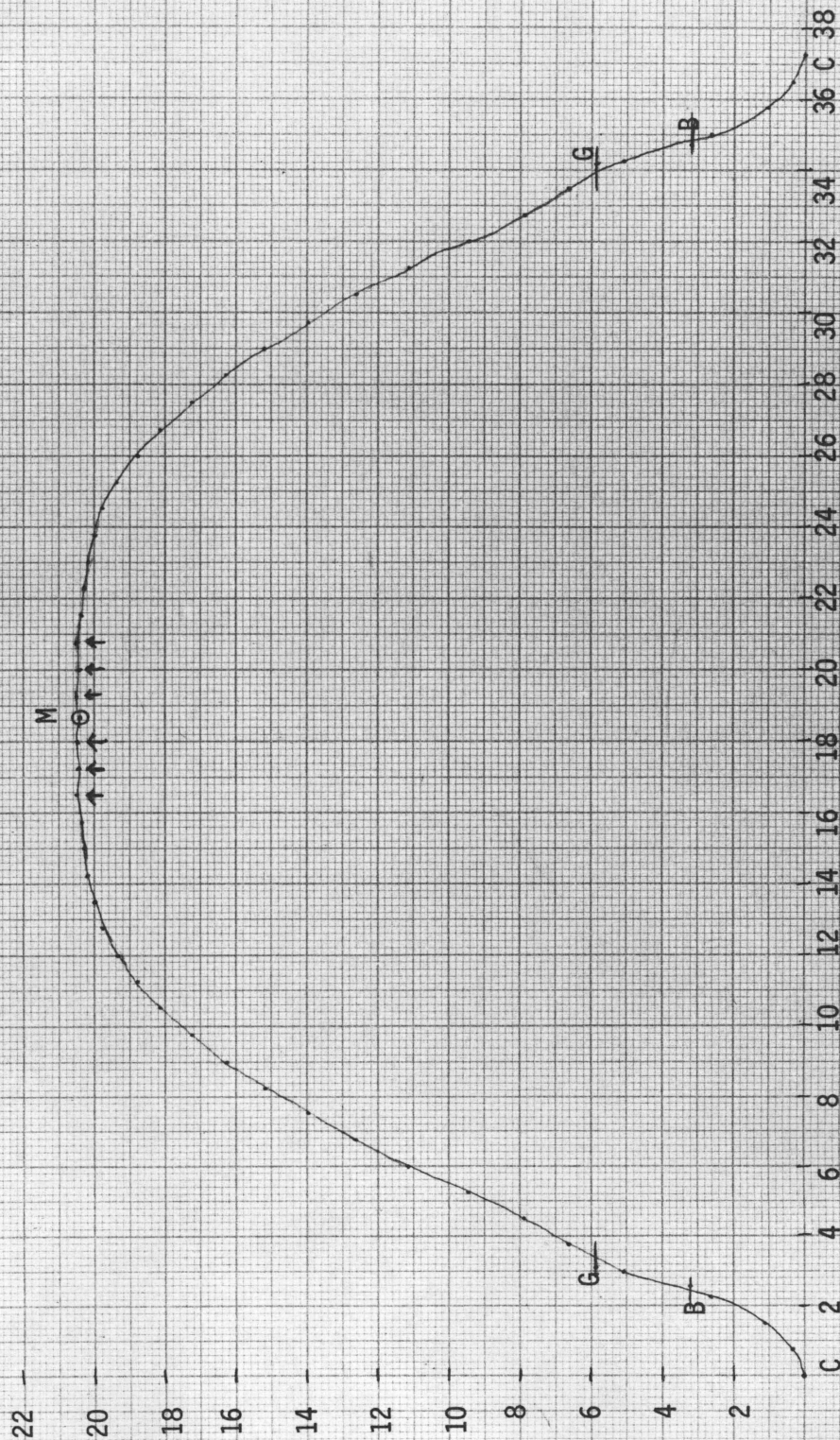
Maxillary Second Bicuspid

All measurements in millimeters.
C=cusp tip, M=midline, G=gingival margin,
B=bracket, ↑=sample size decreased



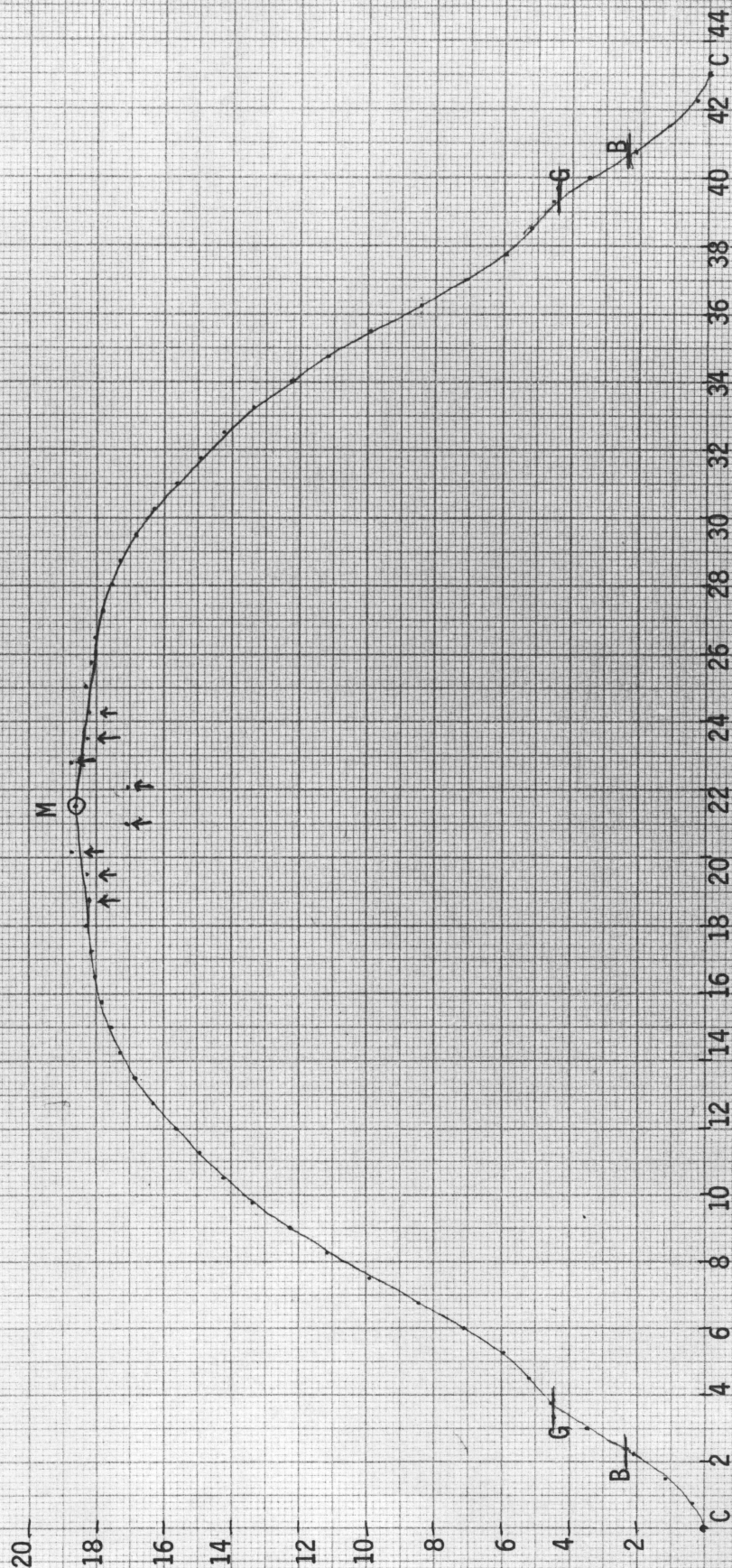
Maxillary First Molar

All measurements in millimeters.
C=cusp tip, M=midline, G=gingival margin,
B=bracket, ↑ =sample size decreased



Maxillary Second Molar

All measurements in millimeters.
C=cusp tip, M=midline, G=gingival margin,
B=bracket, ↓=sample size decreased



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